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DESIGNING SEAPLANE HULLS AND FLOATS

By Lieutenant Benoit

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Among the difficulties encountered by the seaplane builder, one of the greatest is the designing of the hulls and floats. This work requires a great faculty for observation and much experience, because very slight modifications of the shape may make considerable difference in the facility of taking off and in the seaworthiness. This is often the stumbling block of inexperienced or mediocre constructors. Doubtless experimental data, such as the results of tank tests of models, render it possible to predict, at least in principle, as to how a hull or float of a given shape will comport itself. We will see farther along, however, how uncertain these methods are and how they leave room for empiricism, which will reign for a long time yet in seaplane research bureaus.

If we consider a seaplane during the run before the take-off (Fig. 1), we find that it is in equilibrium under the action of certain external forces plus that of inertia. The external forces are:

1. The weight P, a constant force applied at the center of gravity;

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* From "L'Aeronautique," June, 1926, pp. 199-208.

2. The propeller thrust T, whose value diminishes approximately according to a parabolic law $T = T_o - aV^2$ while the speed is increasing;

3. The resultant of the actions of the air on the seaplane, which we will resolve into two forces, the action r on the horizontal tail planes (stabilizer and elevator) and the action R on the rest of the seaplane (wings, hull, engine cockpits, etc.), each of these two forces being itself resolved into a vertical lift and a horizontal drag. These forces increase as the square of the velocity V. Their lines of application are determined by testing a model in a wind tunnel.

4. The resultant H (resolved into a lift H_z and a drag H_x) of the action of the water on the hull. H_z is the buoyant force of Archimedes, which tends toward zero, when the seaplane is taking off, plus a dynamic lift which follows a complex law and whose line of application varies greatly from the beginning to the end of the take-off run. It is largely for the purpose of localizing the dynamic thrust when it reaches a high value, that seaplane hulls are given a longitudinal discontinuity called the step. H can be approximately determined for various values of V by a tank test of a model.

A knowledge of the drags $R_x + r_x$ and H_x, which are all functions of V, renders it possible to draw the curve $f(V)$ of the forces required for propulsion, while a knowledge of the characteristics of the engine and propeller makes it possible

to obtain $g(V)$, the curve of the available forces (Fig. 2).

Since the take-off speed is V_e or the flight speed at the angle of minimum power, it is manifest that the necessary condition for flight is that the curve $f(V)$ be entirely under the curve $g(V)$ from $V = 0$ to $V = V_e$. $f(V)$ presents a maximum for the critical speed ("hump speed" of English writers) comprised between 0 and V_e. The curves f and g may therefore happen to intersect in the vicinity of this speed. The seaplane cannot then exceed the critical speed and it is impossible to take off.

The quality of a hull is sufficiently characterized by the curve f. The more flattened the curve f, the better the corresponding shapes. Since this curve is difficult to plot, one often contents himself with characterizing a hull by the duration of its take-off in still air with a given load. It is then necessary to determine the weights per horsepower and per square meter of the given seaplane.

Since a quick take-off is essential for a seaplane, it is very important that the pilots should have no other troubles. The seaplane must still possess excellent nautical qualities. Lastly, the designer will try to give the hulls such shapes as to enable strong, light and simple construction. The problem is obviously very complex. Before considering it, we will state what is meant by "seaworthiness." It comprises:

1. Ability to navigate, to make evolutions and to be towed in a strong breeze on a rough sea;

2. Ability to take off from a very choppy sea (sea of force 3-4) without throwing much spray, which damages the propellers and controls. It must be possible to take off across the wind, because it is better when there are well-formed waves, to keep the seaplane heading toward them during the whole take-off.

3. Ability to alight on a rough sea without dangerous shocks and without any tendency to ricochet.

The usual method for determining the best shape of a hull or float for a given purpose is that of the test tank. Excepting for a few details of installation, the method is the same as for the study of the hulls of ships but, while for the latter the model is tested under conditions similar to those under which a ship is navigated, the seaplane model is tested under entirely different conditions. In fact:

1. The model is tested at several different speeds, but each time at a constant speed. The forces of inertia are not represented and the conditions of equilibrium of the system are modified;

2. The variable force r, action of the air on the tail group, produced by the pilot during the take-off, is not represented. In a general way, the forces of aerodynamic origin, which greatly affect the trim of the seaplane, are neglected;

3. The model is more a glider than a seaplane. In particular, it does not quit the water and hence the period immediately preceding the take-off cannot be studied.;

4. Study of the alighting is practically impossible;

5. It is impossible to test the seaworthiness;

6. The pitching is not damped by the wings and tail group.

On the whole, the test of a model only poorly represents one special case of employing a seaplane, namely, hydroplaning on still water without the action of the pilot on the controls.

Very many tests of seaplane models have been made in England since 1912, principally in the W. Froude National Tank by Mr. Baker and his assistants. It is undeniable that these tests have had a good effect on the productions of British constructors, but it is none the less certain that some defects in English hulls come from too great faith in the method of testing.

In France a seaplane hull with three steps was built in 1923, after very encouraging tests with a model. This hull, like its model, lifted very quickly, but left the water only with great difficulty. Alighting was very difficult and this hull was destroyed after a score of flights when the water was calm. It is obviously well to be cautious in drawing conclusions from the results of tank tests of models. The principal results obtained in the Froude National Tank were published in the Reports and Memoranda of the British Advisory Committee for Aeronautics

(now the Aeronautical Research Committee).

Another method of studying hulls consists in the use of "albums of hulls" giving a complete summary and forming a convenient reference book on the various types of seaplanes thus far built, both in France and abroad. The number of different seaplane types made in the world between 1912 and 1925 is estimated at 500-600. New types are now being produced at the rate of about 60 a year.

An album of hulls should comprise, for each type of seaplane:

1. A drawing of the hull;

2. A table of characteristics giving the principal dimensions, the angles of incidence of the various elements and certain information concerning the complete seaplane (weight, power, area, etc.).

3. A summary of the results of the tests and of the observations of the parties using the seaplanes.

In such an album it is possible to group the hulls by similarities and draw general laws from their comparison. It amounts, in fact, to an improved empiricism. Obviously such a method cannot revolutionize the science of hydraviation, but it has the merit of avoiding serious defects. This method enabled us in 1922 to design a hull which, after a few retouches, proved to be an appreciable improvement.

A third method, which we proposed and employed in 1922, and whose realization is in progress (the seaplane Romano), is that of full-scale tests with an experimental seaplane designed and built especially for this purpose.

This seaplane which carries a pilot and a passenger, is of low power (150 HP.) and of the central-float type. The float is relatively inexpensive and can be readily replaced by other floats of various shapes and dimensions. The same float can be modified by the addition of caissons or sheathing. The inclination of the float is variable, as well as its distance from the axis of the propeller thrust. Lastly, the principal characteristics of the seaplane (weight, power and even the wing area) can be considerably modified between one test and the next.

The tests comprise the determination of the time required to take off in still air, the estimation of the nautical qualities and various secondary observations (photographs of the wake, registration of the shocks, accelerations, etc.). We can even hope to determine with some degree of accuracy the forces P, T, R and r (Fig. 1) for different speeds. The knowledge of the acceleration (measured with the accelerograph or computed from the law of speeds) renders it possible to determine the unknown force H (resultant of the actions of the water) and to plot the curves $H_1 = f_1(V)$, and $H_2 = f_2(V)$ characteristic of the submerged portion of the float or hull.

The designing of a seaplane comprises the determination of the following elements:

Maximum width or beam;

Length at water line;

Length over all;

Draft of water;

Shape of the bottom of the hull or float.

It would be convenient to be able to determine the principal dimensions approximately by means of formulas, before making the model tests. The estimation of the weight, in particular, presupposes a knowledge of these dimensions. Many formulas have been proposed, and it is no exaggeration to say that each designer employs his own, but that few of them are susceptible of generalization.

The maximum width or beam is usually calculated for a flat bottom and then corrected, if the bottom is V-shaped, by means of the formula $b' = b/\cos^2\alpha$, in which b is the width of the flat-bottomed float, b' the width of the modified float and $180^\circ - 2\alpha$ the angle formed by the straight lines drawn from the keel to the chines (Fig. 3). For a hull or float having a displacement of P (kilograms) the width b (meters) is given, according to some writers, by the formula

$$c = P/b^2 = \text{constant} = 1200,$$

c being termed the "seaplane load index." The values thus

found apply well only to seaplanes of 1500-2000 kg (3307-4409 lb.) having a ceiling of about 5000 m (16400 ft.). Outside of these values, c varies greatly, increasing when P increases. Mr. Blanchard, the well-known French constructor, established an empirical relation, $b^{2.3} = 1130\ P$, which is of wider application than the preceding.

Linton Hope used the formula $b = 0.0365\ (P^2/T_o)^{0.37}$, in which T_o is the nominal horsepower. This formula is not very precise, but seems more logical than the preceding ones, because it contains T_o. The take-off time of a seaplane depends, in fact, not only on the shape of its hull or float, but also on the available power and on its take-off speed. It is even affected, although to a smaller degree, by the efficiency of the propeller at low speeds, by the wing profile and by various other seaplane characteristics.

A formula cannot be logical therefore, unless it contains at least the expressions P/T_o and P/S of the load per horsepower and the load per unit area of the wings. It seemed to us to be of interest to compare, among existing seaplanes, those which have the same value of the term $P/T_o \sqrt{P/S}$, i.e., the same ceiling. The graph representing b in terms of P was found to be practically a straight line having for its equation $b = P/35.8 + 80$ (P in kg, b in cm) with $P/T_o \sqrt{P/S} = 50$ for a biplane. The various points of the graph are all very near a mean straight line and the deviations correspond approxi-

mately to the differences in the take-off qualities. A similar law appears if we express the values of b in terms of P for float seaplanes (having Travemunde or Richardson floats), namely, $b = P/50 + 40$ with $P/T_o\sqrt{P/S} = 45$ for biplanes and 60 for monoplanes. When $P/T_o\sqrt{P/S}$ has a different value from the foregoing, it is only necessary to add a corrective term.

Some constructors keep systematically above these figures. In relaity large floats offer less resistance at low speeds but a considerable resistance at high speeds. They are heavier however, and more difficult to take off.

Length of the water line.- The lengths l_1 and l_2, before and behind the vertical line passing through the center of the hull or float, are determined separately. l_1 must be such that the submerged bow will create a restoring couple sufficient to lessen by several degrees the downward movement due to the propeller thrust in the first phase of taking off, when the speed and, consequently, the hydrodynamic thrust on the front of the hull are still very small. This condition can be expressed by $h\alpha_o n^2 D^4 = K l_1 d$, in which h is the distance from the axis of the propeller to the water line; n, the R.P.M.; D, the diameter of the two-bladed propeller; α_o, a characteristic coefficient of the propeller comprised between 0.012 for slow seaplanes and 0.016 for swift seaplanes; d, the mean width of the hull in front of the center of the submerged portion; K, an empirical constant which appears to have a value of about 220.

Mr. Blanchard established, in an analogous manner, a simpler and more general formula $h = 2.6\ l \sin\gamma$, γ being the angle between the wing chord and the water line.

The length l_2 of the water line behind the center of buoyancy is generally determined by the necessity of balancing the submerged volumes before and behind the center of buoyancy and also by considerations of stability in flight (leverage of the tail group). It also depends on the rear shapes, of which we will speak farther on.

The length L over all is derived from the preceding dimensions, after the designing of the stem has been finished and the tail group has been put in place. Linton Hope, the inventor of flexible hulls, used the formula $L = 0.795 \sqrt[3]{P}$, which can manifestly give only a rough approximation.

The molded depth of a hull or float may vary within quite wide limits. It must be sufficient to give the openings of the hull a free-board of over 80 cm (31.5 in.) and for the reserve buoyancy to be about 250% (assuming all openings capable of being closed water-tight, which is not the case).

Within these limits, save when the hull or float is to be fitted out as a passenger cabin, the depth may be made as small as possible, so as not to increase uselessly the weight and the aerodynamic drag of the float and, in some cases, the distance of the propeller axes from the center of gravity.

Designing the keel and the chines.- This is of capital importance, since the incidences and the radii of curvature greatly affect the ability to take off and also the seaworthiness. It is necessary, when the seaplane hull is under the best angle, for the incidence of the wings to correspond to the flight at minimum power. For this purpose, the mean angle between the keel and chines at the step and the wing chord (defined by the tangent to the intrados) must have a positive value of about 2°. When the hull floats at rest, the mean angle between the keels and the water line must be small (2° or 3°) (Fig. 4).

The changes in the curvature of the keel and chines must be very gradual up to the water line, where the chines must emerge at an angle of $12-20^{\circ}$. The keel, on the contrary, can form a deep stem and cut the water line at an angle approaching 70°.

Drawing the transverse sections.- The shape of the transverse sections somewhat affects the take-off qualities, but has a much greater effect on the throwing of spray and the fatiguing of the hull when the sea is rough.

The bottom of the hull will generally present two symmetrical concave surfaces joined at the keel by an angle or by a convex part with a horizontal tangent. In the sections near the step, the tangents to the section in the vicinity of the chines must be horizontal or even inclined downward (Fig. 3), in order to prevent the throwing of spray. The tangents are gradually

raised as the section considered approaches the stern.

The angles α (already defined) may reach 15-18°. Above the chines, the sections have a more or less polygonal outline. It is advantageous, however, in order to eliminate the weak points which constitute angular assemblages, to join the bottom to the sides by a rather wide rounded strip.

<u>The steps</u>.- Two types of hulls seem to have been definitely adopted: the kind with one step behind the center of gravity and that with two steps. In the latter the principal step is very near the vertical line passing through the center of gravity and the rear step is for the trim. In hydroplaning, it supports only about one-eighth as much as the principal step. The hull with a single step located far enough behind the center of gravity is generally very seaworthy. When such a hull taxies on a rough sea, the contact with the wave crests takes place near the step, which is the part of the seaplane nearest the water. This contact exerts a force passing behind the center of gravity and thus creates a downward couple at the bow (Fig. 5). The seaplane pitches forward gently and thus maintains its speed instead of rebounding dangerously backward, as is the case when the step is located too far forward.

The best location for the step cannot be determined by a simple formula. There are, in fact, no less than four elements to consider: the height of the center of gravity above the bottom of the hull, the height of the propeller, its thrust and the

lift of the tail, account being taken of the effect of the propeller slip stream.

The pilot must be able at any instant, even with the wind aft, to offset the diving moment produced by the lift of the water near the step, by a stalling moment created by the elevator. This limits in practice only the recoil of the step toward the rear. Moreover, it is prudent, on a new type of hull, not to place the step in an extreme position and to retain the possibility of placing "caissons" behind the step, in order to determine the best location.

On hulls with two steps (which are little used in France), the principal step is even with or slightly in front of the center of gravity. The rear step, often consisting of an attached caisson, must be near the water line. Its incidence, when at rest, is small (1 - 2°) and its width about 2/5 that of the principal step.

Designing the rear portion of the hull.- When there is only one step, it is advantageous for the keel and chines to be rectilinear between the step and the stern-post. The chines must be sharp, in order to prevent the tail from being submerged in alighting.

The angle between the keel at the step and the tangent drawn from the step to the tail has been fixed experimentally at 12°. It is advisable not to let it fall below 7°, so that the

pilot will be able to lift the bow sufficiently before taking off.

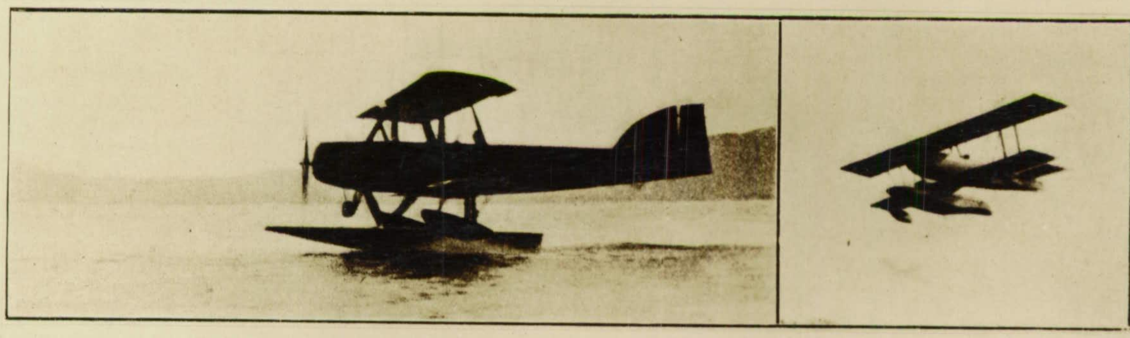
If there are two steps, the tail must be raised freely behind the rear step, 15°, for example. Between the two steps, the hull must be straight and slightly inclined (7-8°) or slightly convex. It is not necessary, in the vicinity, for the chines to have sharp edges. The hull, on the contrary, may present a rounded contour.

It would seem advisable, from the aerodynamic viewpoint, to give the hull a plan shape similar to that of a streamlined body with the least head resistance. Experience has shown, however, that such hulls dip too much and that it is better not to streamline them too much in front. It is also well to draw in the sides slightly behind the step (Fig. 6).

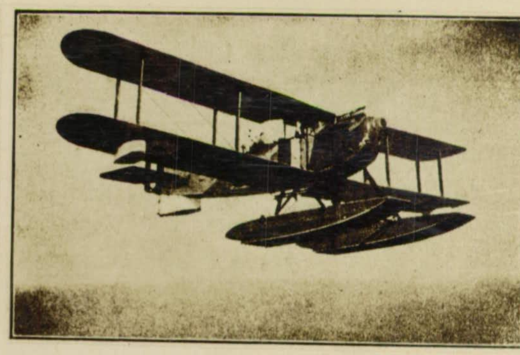
<u>Lateral stability</u>. <u>Wing-tip floats</u>. <u>Fins</u>.- The study of the static or dynamic stability of a floating seaplane comprises the determination of the capsizing couples produced by lateral winds of given velocities and the calculation of the restoring couples, a calculation into which enter only the weight of the seaplane and certain geometric elements of the hull.

The capsizing couples, in terms of the initial inclinations and of the wind velocity, can be determined by testing a model in a wind tunnel by a very simple method. In spite of its importance, this kind of test has never been made.

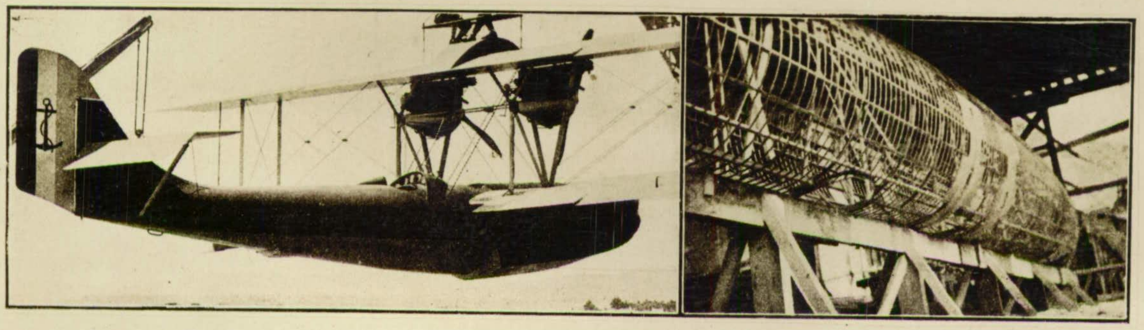
The calculation of the restoring couple peculiar to the given hull is a common practice in naval construction. For a



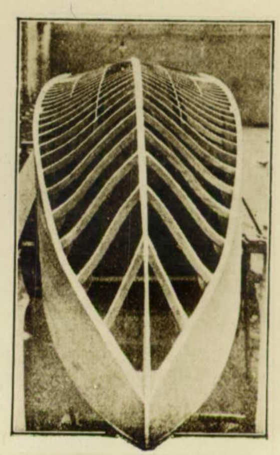
The Romano, a light French airplane, designed for testing full scale floats of various shapes



Floats of a Fairey III-D seaplane



Flexible hull of a Liore' and Olivier seaplane, type 134



Single-step hull of a 760 HP. Latham seaplane under construction

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